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Comparison of High-Strength Steel Pipe and H-Shaped Steel in the Strut of a Braced Wall System

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Abstract

Excavation work accounts for a high percentage of the total building construction cost. The most widely used method for excavation work in an urban area is a braced wall system with struts or rakers. H-shaped steel, which is the most commonly used component for struts in braced wall systems, has disadvantages such as cost-ineffectiveness and increased work interference associated with narrow strut spacing. Therefore, the use of high-strength steel pipe struts in braced wall systems can be an effective alternative to widening the strut spacing. In this study, the construction costs of a braced wall system using H-shaped steel and a braced wall system made with high strength steel pipe were compared by analyzing the required amounts of materials and the construction costs for four practical cases. All analyzed cases considered a change from H-shaped steel to high strength steel pipe in a design change during the construction stage. The results of this study show that the required amount of materials and the construction costs of a braced wall system with high strength steel pipe were lower than those of a braced wall system with H-shaped steel. Consequently, this study suggests that a high strength steel pipe strut is a more economical alternative than an H-shaped steel strut in braced wall systems for deep excavation work.

Keywords: deep excavation; braced wall system; high strength steel pipe strut; H-shaped steel strut

1. Introduction

With economic development and urbanization, buildings tend to become larger. As a result, the excavation work required in urban areas goes deeper and occurs on a larger scale (Ou, 2006). Containing the costs for deep excavation work is very important in terms of total construction cost management because deep excavation accounts for roughly 20% of the total construction cost in building construction (Barrie, 2001). Deep excavation work in an urban area requires a retaining wall and support system to ensure economic feasibility and safety (Tan and Chow, 2008). The retaining wall and support system prevents the collapse of excavated soil around the area due to earth pressure (Macnab, 2002; Kaveh and Abadi, 2011). A braced wall system (BWS) with H-shaped steel (HS) struts or/and rakers has been the most frequently used retaining wall and support system for deep excavation

work in urban areas (Chao *et al.*, 2013) because the strut support system can protect adjacent buildings and utilities, and does not trespass into adjacent subsoil (Finno, 2010). However, a BWS with H-shaped steel (BWS_HS) struts, the most commonly used type of strut member, has poor workability and requires a large amount of steel because the spacing of the post piles and struts is narrow (Kim *et al.*, 2003). These factors can increase the total construction cost.

In the past few years, efforts have been made to mitigate the problems related to using BWS_HS systems. These include developing a new support system and changing the materials used for struts. Kim *et al.* (2005) and Park *et al.* (2009) proposed a new method involving distributing the load of an HS strut to a pre-stressed wale. This method improves workability and decreases the amount of steel required by widening the spacing between struts. Their method also reduces the total construction cost. Another approach is to use high strength steel pipe (HSP) struts in a BWS instead of HS. Choi *et al.* (2013) and Yoo *et al.* (2010) studied the applicability of an HSP support system to verify the effects of widening the spacing interval of struts and post piles. They found that changing the struts to HSP allowed them to widen the strut and post pile spacing. In addition, there have been studies of the other effects of using HSP struts (Choi *et al.*, 2007; Na *et al.*, 2008;

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Yoo *et al.*, 2010; Choudhury *et al.*, 2013). Most of the researchers (Choi *et al.*, 2007; Na *et al.*, 2008; Yoo *et al.*, 2010; Choudhury *et al.*, 2013) have evaluated the structural stability of HSP; however, there have not been any studies evaluating the economic effects of changing the strut material.

In this study, retaining wall work was not estimated when comparing the required amount of steel and construction costs for the cases considered. The comparison considered only the costs and work required to install and demolish struts with the change in materials. The purpose of this study is to compare and analyze the cost savings by using HSP as the material of a strut support system for retaining work in an urban area. The cost savings were analyzed by comparing the amount of steel required in the construction costs for an actual case that was designed for both HSP and HS struts.

2. Strut Support System of a Retaining Wall

Struts or rakers are the most widely used support members for retaining walls in deep excavations in urban areas (Chao *et al.*, 2013). A strut is a horizontal compression element that provides lateral support by bracing a portion of one wall against another portion (Puller, 2003). Struts are more widely used than rakers in a support system in a BWS (Chao *et al.*, 2013). Their use is not restricted to a certain depth of excavation, and they are comparatively simple to construct and use regardless of soil conditions (Kim *et al.*, 2003). The most commonly used material for steel struts is HS. HS struts have the advantage of being widely available, and they can be reused (Macnab, 2002). However, they have the disadvantages of poor workability and high construction cost, and require an additional process for their installation because of their narrow spacing (Kim *et al.*, 2005). In addition, bracing is a component that may act as an obstacle to deep excavation work and the construction of the structure (Choudhury *et al.*, 2013). Bracing can also increase construction costs because it requires more steel.





In the past few years, considerable research has been conducted to address the disadvantages of using HS struts (Kim *et al.*, 2005; Park *et al.*, 2009; Yoo *et al.*, 2010; Choudhury *et al.*, 2013). Among traditional materials for struts such as HS, HSP struts are considered to be the best alternative (Yoo *et al.*, 2010). Although there have been many actual applications of HSP in construction, and research on the structural stability of HSP struts is readily available, a verification of the economic effects of using HSP struts has not yet been performed.

3. Features of a High Strength Steel Pipe Strut System

3.1 Structural Characteristics of the Material Used

A high strength steel pipe strut system (HSPS) is a BWS that uses HSP struts instead of HS struts. The structural characteristics of HSP and HS struts are summarized in Table 1. (Yoo *et al.*, 2010).

Table 1. Structural Characteristics of Materials Used

| Strut type | HSP | HS |
|--------------------------|--|---|
| Isometric view |  |  |
| Construction photo |  |  |
| Steel grade for strut | STKT590, $\Phi 406.4 \times 7t$ | H-300 \times 300 \times 10 \times 15 |
| Yield strength (F_y) | 440 MPa | 240 MPa |
| Moment of inertia | $I_y = I_z = 17.519 \text{ cm}^4$ | $I_y = 20.40 \text{ cm}^4$, $I_z = 6.750 \text{ cm}^4$ |
| Unit weight | 68.9 kg/m | 94 kg |
| Maximum spacing | 14 m | 9 m |

The grades of steel listed in Table 1. are the most widely used materials for struts. HS struts have poor buckling and torsional stiffness characteristics because of an unfavorable anisotropic cross-section with respect to the weak axis. In addition, they require the installation of additional horizontal and vertical bracing during construction. However, the HSPS has a favorable anisotropic cross-section with respect to buckling and torsional stiffness, so no additional bracing is required. HSP struts also have the advantage of cost savings because of the reduced amount of steel required with the wider spacing of the struts or post piles. Therefore, changing struts from HS to HSP provides economic benefits, and improves structural stability and construction workability.

3.2 Components of HSPS

The HSPS proposed in this study has a different connection method for reducing steel usage. As shown in Fig.1., the proposed connection method for an HSP strut is a component part. The existing connections for steel pipe struts can be classified into two types. One connection requires that a bolt be tightened after welding the end of the flange. The other connection requires that steel pipes be welded together. The disadvantage of these connections is the increase in construction cost due to the loss of steel: these connections make it impossible to reuse the struts without shortening their length and repeating the work required to reconnect them.

The proposed connection components of an HSPS were devised to compensate for the disadvantages of the traditional connection methods required to install HS struts, as shown in Fig.1. For example, to reuse an HS strut, workers must cut off the existing connection and drill new holes to tighten the bolt. These proposed connection components for installing HSP struts

minimize the loss of steel. In addition, they can also be used as stiffeners for damaged steel pipe.

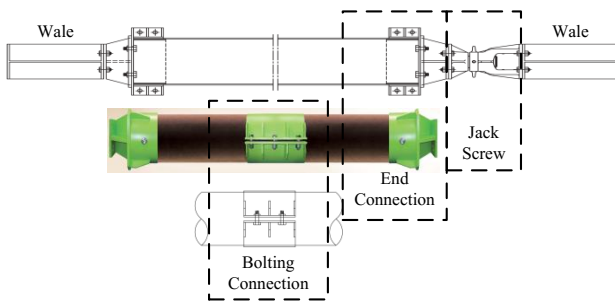


Fig.1. Components of HSPS

4. Case Study

4.1 Case Descriptions

This study analyzed four cases located in an urban area to validate cost savings by comparing the change in the required amount of steel when HS struts are replaced with HSP struts. The four cases had BWS_HS struts specified during the initial design stage. However, the retaining wall system was redesigned to reduce costs and shorten the construction period before the start of construction; that is, the struts were changed from HS to HSP. This change was expected to improve the constructability of the structural framework in the substructure.

Table 2. gives the design profile of the bracing wall and support system for the four cases. The post pile or the horizontal and vertical strut spacing was the maximum value in the range for obtaining the required stability of the retaining wall. Table 3. shows a comparison of the plans for the retaining walls in the

four cases in which both HSP and HS were used for the horizontal struts. As shown in Tables 2. and 3., HS struts were installed in double rows, whereas the HSP struts were installed in a single row. The horizontal spacing of the struts was widened by approximately 0.51 m for the HSP struts. The vertical spacing was identical, except in Case 1. For Case 1, the vertical spacing of the struts was set 0.5 m wider. As illustrated in Table 3. for Case 1, the number of strut rows was reduced from nine to eight. However, post piles require significant differences in spacing, unlike struts. The post pile spacing was widened by 2.1 m in Case 4 (the case with the greatest difference in spacing) when using HSP instead of HS struts. On the other hand, Case 1 showed the smallest difference in post pile spacing. As shown in Table 3. for Case 1, the number of post piles installed was reduced from eight to seven for HSP struts.

4.2 Analysis of Cases

By changing the struts from HS to HSP, the number of struts required was decreased because their horizontal spacing, or the post pipe spacing was increased. Case 1 (Detail of Changed Materials) is described in Appendix 1. As shown in Table 4., the amount of steel required for struts, post piles, and bracing decreased. Except for Case 1, the required number of steel struts decreased by an average of 42.41% because 73% of the unit weight of HSP was compared to HS struts. Double rows were required in the design of the HS struts, whereas a single row was required in the design of the HSP struts. Thus, HS struts required almost twice as much steel as HSP struts.

Table 2. Description of Cases

| Cases | Location | Type of building | No. of basement story | No. of story | No. of adjacent building | Strut type | Area (m ²) | Depth (m) | Retaining structure | No. of strut row | Strut spacing (m) | | | Bracing |
|--------|----------|-------------------|-----------------------|--------------|--------------------------|------------|------------------------|-----------|-----------------------------|------------------|-------------------|----------|-----------|---------|
| | | | | | | | | | | | Horizontal | Vertical | Post pile | |
| Case 1 | Seoul | Hospital | 5 | 6 | 1 | HSP | 4,900 | 35.0 | C.I.P. | Single | 5.0 | 3.5 | 6.0 | X |
| | | | | | | HS | | | | Double | 5.0 | 3.0 | 5.5 | O |
| Case 2 | Seoul | Culture Centre | 3 | 3 | 6 | HSP | 2,136 | 40.6 | H-pile+earth retaining wall | Single | 3.5 | 3.0 | 5.2 | X |
| | | | | | | HS | | | | Double | 3.5 | 3.0 | 4.5 | O |
| Case 3 | Seoul | Industrial Centre | 4 | 12 | 1 | HSP | 2,126 | 17.4 | H-pile+earth retaining wall | Single | 4.0 | 2.7 | 8.5 | X |
| | | | | | | HS | | | | Double | 4.0 | 2.7 | 6.5 | O |
| Case 4 | Suwon | Shopping centre | 3 | 9 | 1 | HSP | 880 | 12.8 | H-pile+earth retaining wall | Single | 4.0 | 3.0 | 7.6 | X |
| | | | | | | HS | | | | Double | 3.0 | 3.0 | 4.5 | X |

Table 3. Comparison of HSP and HS Plans and Sections

| Cases | HSP strut | | HS strut | |
|--------|-----------|---------|----------|---------|
| | Plan | Section | Plan | Section |
| Case 1 | | | | |
| Case 4 | | | | |

Unlike the other cases, the amount of steel required to change from HS to HSP struts in Case 1 increased—Case 1 was designed to use HS struts with earth anchors. The amount of steel listed for Case 1 in Table 4. does not include the amount of steel required for the earth anchor. The required amount of steel for the post pile decreased by an average of 21% when using HSP struts because the use of post piles realized the largest difference in spacing with the change. Additional bracing was used in the HS cases for structural stability.

Table 4. Comparison of Material Amounts for HSP and HS

| Cases | HSP (A) (ton) | HS (B) (ton) | (A-B)/B×100 (%) | |
|-------|---------------|--------------|-----------------|--------|
| 1 | Strut | 815.55 | 763.30 | +6.85 |
| | Post pile | 364.30 | 486.00 | 25.04 |
| | Bracing | N/A | 150.96 | 100.00 |
| | Subtotal | 1,179.85 | 1,400.27 | 15.74 |
| 2 | Strut | 114.62 | 295.60 | 61.23 |
| | Post pile | 17.79 | 20.50 | 13.24 |
| | Bracing | N/A | 11.55 | 100.00 |
| | Subtotal | 132.42 | 327.66 | 59.59 |
| 3 | Strut | 315.67 | 662.12 | 52.32 |
| | Post pile | 212.59 | 221.48 | 4.01 |
| | Bracing | N/A | 83.15 | 100.00 |
| | Subtotal | 528.27 | 966.75 | 45.36 |
| 4 | Strut | 67.53 | 182.28 | 62.95 |
| | Post pile | 12.72 | 21.20 | 40.03 |
| | Bracing | N/A | N/A | 0.00 |
| | Subtotal | 80.25 | 203.48 | 60.56 |
| Total | | | 45.31% | |

Table 5. Comparison of Construction Costs for HSP and HS

| Cases | HSP (A) | HS (B) | (AB)/B×100 | |
|-------|--------------------------|-----------|------------|---------|
| 1 | Construction cost (US\$) | 2,278,547 | 2,537,952 | 259,405 |
| | Percentage (%) | 89.78 | 100.00 | 10.22 |
| 2 | Construction cost (US\$) | 171,046 | 258,699 | 87,650 |
| | Percentage (%) | 66.12 | 100.00 | 33.88 |
| 3 | Construction cost (US\$) | 631,031 | 747,439 | 116,408 |
| | Percentage (%) | 84.43 | 100.00 | 15.57 |
| 4 | Construction cost (US\$) | 71,989 | 132,054 | 60,065 |
| | Percentage (%) | 54.51 | 100.00 | 45.49 |
| Total | | | | 26.30 |

Table 5. details the cost savings related to the installation and demolition of a strut system. Case 1 (Detail Cost Criteria) is shown in Appendix 2. By using HSP struts, construction costs can be reduced by an average of 26.3%. Case 4 shows a reduction of 60.56% of the amount of steel required, and shows the best reduction in construction cost as well. Overall, the average cost savings of Case 4 was smaller than the percentage shown for the reduction of required steel because the unit price of HSP struts was higher than that of HS struts.

5. Discussion

Cost savings and shortened construction time were achieved by using BWS_HSP struts. This was realized by a reduction in the number of strut members required (i.e., struts, post piles, and bracings) and thus the amount of materials necessary, and a reduction in the time required to install them. Although beyond the

scope of this study, the time required for excavation work was shortened with the change in strut material. HSP struts will also improve construction efficiency in excavation work because bracing might not be required when struts are more widely spaced. If the installation of bracing is not required, dangerous high altitude work would be unnecessary and the resulting construction process would be much faster. Widened strut or post pile spacing also allows for faster installation because large drilling excavation equipment with less interference can be used.

The safety of the excavation work and the structural framework is improved with the use of HSP struts. The reduction in potential accidents in excavation work is due to the following reasons: (1) the number of struts installed and dismantled was reduced, (2) the available working space was increased during excavation work, and (3) the workers could not work above the struts because of the curvature of the steel pipe. Consequently, the use of HSP struts has the advantages of less steel required, cost savings, reduced installation/demolition time, and improved construction efficiency and safety. These results can provide practitioners with useful guidance for excavation work.

6. Conclusion

The most widely used retaining system in excavation work is the BWS_HS system, which has the disadvantages of poor workability and a larger amount of steel required due to the narrow spacing of the post piles and struts. To improve construction efficiency during the installation of a BWS system, this study proposes that the struts be changed from HS to HSP. In this study, this study compared the required amount of steel and the construction costs for HSP struts and HS struts. The results of the comparison for four cases showed that selecting an adequate material for struts is one of the most important factors for realizing cost savings in excavation work. The following are important advantages of using HSP struts: their use (1) reduces the required amount of steel for struts, post piles, and bracings, (2) reduces total construction costs, (3) shortens the construction period for BWSs, and (4) improves construction efficiency and safety during excavation work.

However, prior to the wide spread practical application of HSP struts for these reasons, additional research is required. This study only compared the construction costs. Therefore, additional steel members, such as wales and earth anchors, should be considered in the comparison of the required amount of steel. In addition, this study only considered the most widely used steel grades. Future work should consider various grades of steel in order to understand their effects on these results.

Appendix 1: Quantitative Comparisons of Material Quantities

Table 1.-a. Quantitative Comparisons of H-pile (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Variation |
|----------------------|----------------|------|-----------------------------------|-------------------|-----------|
| | | | Quantity | | |
| H-Pile boring (Φ450) | Silt | M | 677 | 666 | 11 |
| | Weathered rock | M | 182 | 263 | -81 |
| | Soft rock | M | 2,455 | 3,903 | -1,448 |
| H-Pile boring (Φ400) | Silt | M | 63 | - | 63 |
| | Weathered rock | M | 17 | - | 17 |
| | Soft rock | M | 228 | - | 228 |
| H-Pile embed/drawing | | M | 3,622 | 4,832 | -1,210 |
| H-Pile connect | | EA | 332 | 421 | -89 |

Table 1.-b. Quantitative Comparisons of Wale (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Variation |
|---------------------------|-----------------|------|-----------------------------------|-------------------|-----------|
| | | | Quantity | | |
| Wale install/dismantle | H-300×300×10×15 | M | 2,864 | 2,847 | 17 |
| Wale connect | H-300×300×10×15 | EA | 285 | 352 | -67 |
| Bracket install/dismantle | L-100×100×10 | M | 1,591 | 1,644 | -53 |

Table 1.-c. Quantitative Comparisons of Strut (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Variation |
|--|---------------------------------|------|-----------------------------------|-------------------|-----------|
| | | | Quantity | | |
| Strut install/dismantle | H-300×300×10×15 | M | 174 | 7,589 | -7,415 |
| Strut connect | - | EA | - | 1,395 | -1,395 |
| High strength steel pipe install/dismantle | Φ406.4-7T | M | 10,825 | - | 10,825 |
| Center joint install/dismantle | Steel pipe+steel pipe | EA | 749 | - | 749 |
| End connect install/dismantle | Steel pipe+wale | EA | 784 | - | 784 |
| Fixing band install/dismantle | Steel pipe+bearing support beam | EA | 1,561 | - | 1,561 |
| Bracing | L-100×100×10 | M | - | 9,450 | -9,450 |
| Bearing support beam install/dismantle | H-298×201×9×14 | M | 4,680 | 9,314 | -4,634 |
| Bearing support beam connect | - | EA | 400 | - | 400 |
| Stiffener | - | EA | 1,752 | 978 | 774 |
| Jack install/dismantle | 100 Ton | EA | 399 | 255 | 144 |
| Corner strut install/dismantle | - | EA | - | 748 | -748 |
| Piece bracket install/dismantle | - | EA | 1,016 | 1,499 | -483 |

Table 1.-d. Quantitative Comparisons of Subsidiary Work (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Variation |
|-----------------------------------|----------|------|-----------------------------------|-------------------|-----------|
| | | | Quantity | | |
| Still materials/still pipe convey | Return | M/T | 1,959 | 2,455 | -496 |
| Still pipe convey | One way | M/T | 45 | 615 | -570 |

Appendix 2: Comparisons of Construction Cost

Table 2.-a. Comparisons of H-pile Cost (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Cost variation (won) |
|----------------------|----------------|------|-----------------------------------|-------------------|----------------------|
| | | | Cost | | |
| H-Pile boring (Φ450) | Silt | M | 10,170,500 | 10,987,350 | 183,150 |
| | Weathered rock | M | 9,100,000 | 13,160,000 | -4,060,000 |
| | Soft rock | M | 171,850,000 | 110,166,000 | 61,684,000 |
| H-Pile boring (Φ400) | Silt | M | 1,039,500 | - | 1,039,500 |
| | Weathered rock | M | 850,000 | - | 850,000 |
| | Soft rock | M | 15,960,000 | - | 15,960,000 |
| H-Pile embed/drawing | | M | 21,732,000 | 28,989,000 | -7,257,000 |
| H-Pile connect | | EA | 13,280,000 | 16,840,000 | -3,560,000 |
| Total | | | 244,982,000 | 18,142,350 | 64,839,650 |

Table 2.-b. Comparisons of Wale Cost (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Cost variation (won) |
|---------------------------|-----------------|------|-----------------------------------|-------------------|----------------------|
| | | | Cost | | |
| Wale install/dismantle | H-300×300×10×15 | M | 42,960,000 | 42,705,000 | 255,000 |
| Wale connect | H-300×300×10×15 | EA | 7,125,000 | 8,800,000 | -1,675,000 |
| Bracket install/dismantle | L-100×100×10 | M | 11,137,000 | 11,508,000 | -371,000 |
| Total | - | - | - | 63,013,000 | -1,791,000 |

Table 2.-c. Comparisons of Strut Cost (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Cost variation (won) |
|--|---------------------------------|------|-----------------------------------|-------------------|----------------------|
| | | | Cost | | |
| Strut install/dismantle | H-300×300×10×15 | M | 2,610,000 | 136,598,400 | -7,415 |
| Strut connect | - | EA | - | 41,850,000 | -1,395 |
| High strength steel pipe install/dismantle | Φ406.4-7T | M | 184,025,000 | - | 10,825 |
| Centre joint install/dismantle | Steel pipe+steel pipe | EA | 22,470,000 | - | 749 |
| End connect install/dismantle | Steel pipe+wale | EA | 15,680,000 | - | 784 |
| Fixing band install/dismantle | Steel pipe+bearing support beam | EA | 12,488,000 | - | 1,561 |
| Bracing | L-100×100×10 | M | - | 94,500,000 | -94,500,000 |
| Bearing support beam install/dismantle | H-298×201×9×14 | M | 65,520,000 | 130,394,600 | -64,874,600 |
| Bearing support beam connect | - | EA | 8,000,000 | - | 8,000,000 |
| Stiffener | - | EA | 8,760,000 | 4,890,000 | 3,870,000 |
| Jack install/dismantle | 100Ton | EA | 5,985,000 | 3,825,000 | 2,160,000 |
| Corner strut install/dismantle | - | EA | - | 26,180,000 | -26,180,000 |
| Piece bracket install/dismantle | - | EA | 30,480,000 | 44,970,000 | -14,490,000 |
| Total | | | 356,018,000 | 483,208,000 | -127,190,000 |

Table 2.-d. Comparisons of Subsidiary Work Cost (Case 1)

| Work information | Standard | Unit | High strength steel pipe (change) | H-beam (existing) | Cost variation (won) |
|-----------------------------------|----------|------|-----------------------------------|-------------------|----------------------|
| | | | Cost | | |
| Still materials/still pipe convey | Return | M/T | 78,358,400 | 98,182,000 | -19,823,600 |
| Still pipe convey | One way | M/T | 909,400 | 12,300,200 | -11,390,800 |
| Etc. | - | - | 2,000,000 | - | 2,000,000 |
| Total | - | - | 81,267,800 | 110,482,200 | -29,214,400 |

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